Advanced Mini Array Antenna Design Using High Fidelity Computer Modeling and Simulation:

Dr. Charles W. Manry Jr., Kianoush Rouzbehani, Dean Nathans
SPAWAR Systems Center - San Diego

Dr. Alison Brown, Dr. H.-W. Tseng, Sheryl Atterberg, *NAVSYS*

BIOGRAPHY

Dr. Charles Manry Jr. began working for the department of Navy at SPAWAR Systems Center San Diego in 1996. He has a Ph.D. in Electrical Engineering form Washington State University. His work includes numerical simulation of antennas and complex platforms for EMC/EMI prediction and antenna performance. He has been part of the EIGER EM tool development effort and has for the last two years been awarded DoD Supercomputer Challenge Status to run problems of interest to the Navy.

Kianoush Rouzbehani attended California State University in Los Angeles, majoring in Electrical Engineering. He graduated in June 1999, receiving a Master Degree. Upon graduation Kianoush accepted a position at Space and Naval Warfare System Center, San Diego. He is currently a member of Topside Design Team in Applied Electromagnetics Branch. His areas of responsibilities include EMI evaluation and EME analysis and antenna performance prediction.

Dean Nathans is the Head of the GPS Product Development Team, GPS and Navigation Systems Division, SPAWAR Systems Center San Diego. Mr. Nathans's leads GPS Programs in support of the Navy’s Navigation Program Office, GPS Joint Program Office, and the Office of Naval Research, including Navigation Warfare, A/J Antenna Development, GPS Augmentation, and GPS Test Fixture development. Mr. Nathans has twenty-three years of experience in Communication and Navigation Research and Development. Mr. Nathans received his BSEE from Rutgers College of Engineering and MEE from Villanova University. He is a Registered Professional Engineer.

Dr. Alison Brown is the President and CEO of NAVSYS Corporation. She has a Ph.D. in Mechanics, Aerospace, and Nuclear Engineering from UCLA, an MS in Aeronautics and Astronautics from MIT, and an MA in Engineering from Cambridge Univ. In 1986 she founded NAVSYS. Currently she is a member of the GPS-III Independent Review Team and Scientific Advisory Board for the USAF and serves on the GPS World editorial advisory board.

Dr. Huan-Wan Tseng is an Antenna & RF Engineer at NAVSYS Corporation. He has a Ph.D. from Ohio State University, an ME from University of Florida, and a BS from Tatung Institute of Technology (Taipei, Taiwan), all in Electrical Engineering. He is responsible for the development of novel GPS antenna arrays at NAVSYS.

Sheryl Atterberg is a Product Manager at NAVSYS Corporation for Receivers, Antennas, and Data Loggers. Sheryl has a MS from Kansas State University (KSU) in Economics/ Industrial Engineering and BS degree in Engineering also from KSU. She had worked over 15 years at Lockheed Martin prior to joining NAVSYS.

ABSTRACT

NAVSYS has developed a miniaturized GPS antenna array technology that reduces the size of the antenna elements and the array dimensions. This is an enabling technology, which allows GPS controlled reception pattern antenna arrays (CRPA) with anti-

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jamming capability to be installed on vehicles where their size has previously prohibited their use. This includes aircraft where size and weight constraints resulted in fixed reception pattern antenna (FRPA) installations instead of CRPAs and in munitions applications where space and surface area are at a premium.

NAVSYS has developed a six-inch L1 four element phased array antenna. However, there is still a need for even smaller mini-array antenna with more elements and both L1/L2 capability. NAVSYS and SPAWAR have teamed to use the NAVSYS antenna design and the Department of Defense's supercomputer power along with Electromagnetic Interactions GEneRalized (EIGER) code which is an advanced Method of Moment/Hybrid Finite Element Method to model the antenna and compare the results to test data. This paper will present the results of the modeling data versus test data and the results of a potential design modification.

INTRODUCTION

Many of the smaller munitions in operation or in development do not have a form factor that allows for a conventional CRPA to be installed. Because of size and weight constraints, some host aircraft within the Air Force and Navy have also elected to install FRPA antennas which cannot provide the A/J protection needed in many tactical environments. The GPS mini-array will enable A/J capability to be provided on many small munitions, aircraft and other host vehicles where the size and weight of the conventional CRPA array has previously been prohibitive.

A key factor in the array performance is the number of antenna elements. The more elements available, the more precisely a null can be steered in the direction of a jammer, improving the overall SNR and also allowing flexibility in placing nulls on jammers. The number of jammers, which can be nulled by a GPS array, is equal to one less than the number of antenna elements (N-1). The more elements in a beam forming or null forming array, the greater the degree of directionality in the array and the greater the gain in the direction of the desired signals.

To prevent spatial correlation, the antenna array elements in a conventional array must be placed half a wavelength apart. This changes the relative phase shift between elements as a function of the input signal elevation angle so that there is no phase shift (0^o) when the signal is perpendicular to the array and a half cycle phase shift between elements (180^o) when the signal is horizontal to the array.

It is possible to shrink the size of the individual antenna elements by designing small patch elements using a high dielectric substrate. This will allow more antenna elements to be clustered closer together in the same over-all array footprint. The major innovation presented in this research effort is the introduction of a shaped high-dielectric superstrate, which allows reduction in the mutual coupling between elements and the same half-cycle phase relationship to be maintained between antenna elements as in a full-size array. The combination of these effects enable the over-all size of a GPS antenna array to be shrunk while still providing equivalent A/J protection to a full-size conventional GPS CRPA. This will allow the existing 7-element CRPA array of 14-inch diameter to be reduced to less than 6 inches in diameter.

The miniature array is composed of a ground plane, a substrate with the antenna elements on its surface, and a superstrate on top of the elements. The dielectric constant of the substrate is increased so that the size of the antenna elements can be reduced. By controlling the design of the antenna elements, the efficiency is increased so that they have the same gain as a standard GPS antenna element. By adjusting the dielectric constant and shape of the superstrate, the mutual coupling between the antenna elements is minimized and the reduced antenna spacing is scaled so that it appears to be effectively $\lambda/2$ in its beamforming or null steering performance. However, the shape of the superstrate has an appreciable effect on the shape of the individual element patterns and must be taken into account.

One configuration of the NAVSYS Mini-Array is show in Figure 1.

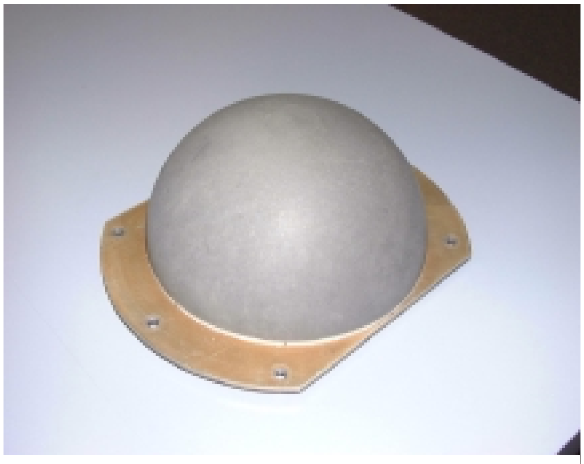

Figure 1: NAVSYS Six Inch Mini Array

USE OF EIGER FOR MODELING LENS EFFECTS AND SIMULATE ANTENNA ELEMENTS

To study the NAVSYS antenna and the effects of the lens superstrate a powerful computational tool is being used in conjunction with the computational horsepower provided by DoD supercomputers. This work is being carried out at the Navy's SPAWAR System Center laboratory in San Diego, California. The tool being used is known as EIGER (Electromagnetic Interactions GEneRalized) and is a continuing development between the DoE and the DoD [1-2]. EIGER is a hybrid FEM/MoM code of unprecedented capability. The current and future capabilities of this tool are due to the approach of describing electromagnetics as a set of generalized operators and concepts [3]. From this approach an object-oriented code was developed that captures these operators and concepts with an excellent ability to describe and solve electromagnetic problems [4].

The key concept used with the NAVSYS antenna is the use of regions. A region in EIGER is a bounded volume in space. The region's properties then define the use of a specific Green's Function to govern the propagation of energy. Usually it is either a homogeneous Green's Function or a layered media Green's Function. The flexibility of EIGER is that you can have separate regions, with different Green's Functions, in the same problem. Two regions can then be coupled together by the use of boundary conditions that are enforced along a common surface shared by two regions. This surface can be a dielectric boundary or an air aperture. The air aperture is a fictitious surface that is introduced into a problem to force the formation of two separate regions from what normally would be one region. This allows the user of EIGER added flexibility in

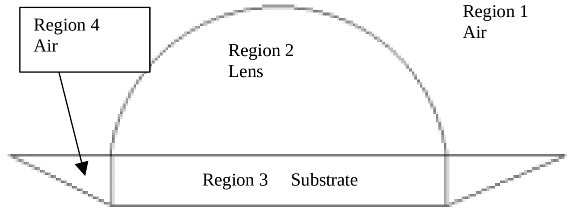

Figure 2: The separate regions used in the NAVSYS EIGER simulation. The region number and the dielectric material are shown. Not draw to scale.

solving electromagnetic problems. The electromagnetic principle involved in the use of regions in this manner is the use of the equivalence theorem [5]. Equivalence theorem allows one to replace a dielectric boundary or air aperture surface between regions with its equivalent electric and magnetic currents on the surface. Separate current solutions are required on each side of the surface.

For the NAVSYS Antenna the FEM capability in EIGER was not used due to the fact that the problem easily breaks down into four MoM regions (see Figure 2). These regions are the external region that is the volume from the outer surfaces of the antenna to infinity (region 1), inside the lens superstrate (region 2), inside the substrate (region 3), and a fourth region. Region 2 contains the top part of the patch, the inside surface of the lens, and the top of the boundary between the lens superstrate and the substrate. Region 3 contains the bottom of the boundary between the lens superstrate and the substrate, the top side of the base plate, the feed wires that come through the base plate and attach to the patches, the bottom of the patches, and the vertical surface that separates region 3 and 4. This surface represents the boundary between the exposed dielectric surface of the substrate and the outside air.

To couple regions 2 and 3 together the boundary between the lens and the substrate is modeled by using separate equivalent electric and magnetic currents at the non-conducting boundary or surface in each region. For this problem the patches are meshed using triangular elements. For the patches and the feed wires the Electric Field Integral Equation (EFIE) was used. The dielectric surface between regions 2 and 3 is also meshed with triangular elements. Each side of the dielectric surface is modeled with dielectric boundary MoM elements and has a separate set of unknowns unique for each region as mentioned above. The integral equation used to enforce the boundary conditions on the surface between regions 2 and 3 (and 3 and 4) is known as the PMCHW equation [1, 3]. This integral equation is used heavily

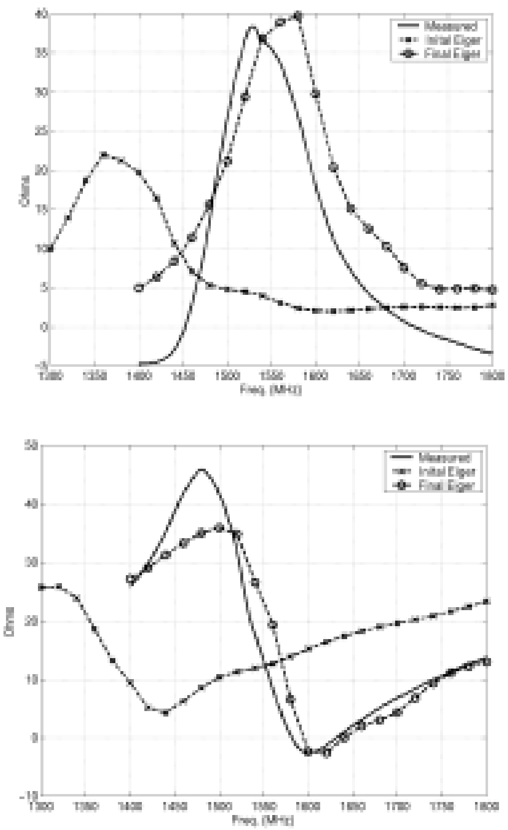

Figure 3: Input impedance for patch element 1. Measured data and the initial and final EIGER model results are shown.

for this problem. Throughout the model linear basis functions are used to represent the currents. Region 4 contains the bottom of the ground plane (assumed to be infinitely thin), the outside surface of the exposed substrate, and an introduced air aperture to force the formation and separation of region 4 and region 1. As mentioned above all the surfaces are meshed using triangular elements. The feed wires are model using thin wire segments with only one segment used for each of the four feed wires. The total number of elements is approximately 8,000 elements with the number of unknowns being approximately 21,000-28,000. The large number of unknowns is due mainly to the use of the PMCHW equations that cause 12 unknowns (3 electric and 3 magnetic basis current functions on each side) to be used for each triangular element that couples the separate regions together. The NAVSYS EIGER model was solved using 16 nodes with 4 processors per node (64 CPU's total) on an IBM Power3 SMP (one quarter of the machine used) and took approximately one hour (wall time) to solve per frequency

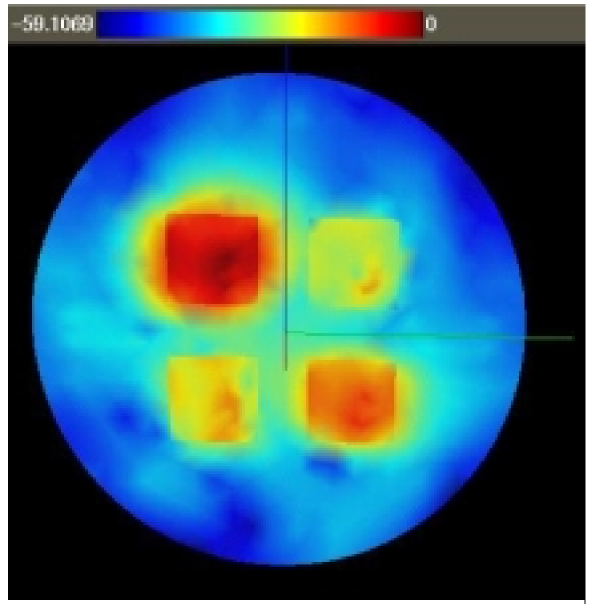

Figure 4: Current Intensity Due To The Excitation Of Patch Element 1. A dB Scale Is Used With The Largest Current Set At 0db.

ORIGINAL HEMISPHERICAL LENS SUPERSTRATE RESULTS

The original configuration of the NAVSYS antenna has been modeled using EIGER. Missing from this model is the eight screws that we added later to strengthen the attachment of the lens to the substrate during flight-testing. The addition of these screws will be done in future work. The ground plate modeled is 6" in radius. To approximate the measured results of this antenna configuration the patches had to be trimmed down from the values used in the actual antenna. This was also done so that the patch would be near resonance at L1. To accomplish this the size of the patches was trimmed by 2% by reducing the length of the patch near the feeds. The input impedance of patch element number 1 is shown in figure 3. In this figure the measured impedance (solid line), the initial EIGER impedance using the original dimensions for the patches (dashed-X marked line), and the final 2% trimmed EIGER impedance (dashed circle marked line) are shown. It is very interesting to note how such a small change in the size of the patch has such a large impact on the impedance. The current distribution images (region 2 only) are shown in figure 4. The currents on the dielectric surfaces are not shown nor are the triangle elements that represent these surfaces. The excited patch is visibly discernable as well as the feed lines. The dB scale shown is normalized to 0 using the maximum current in the display. The coupling is on

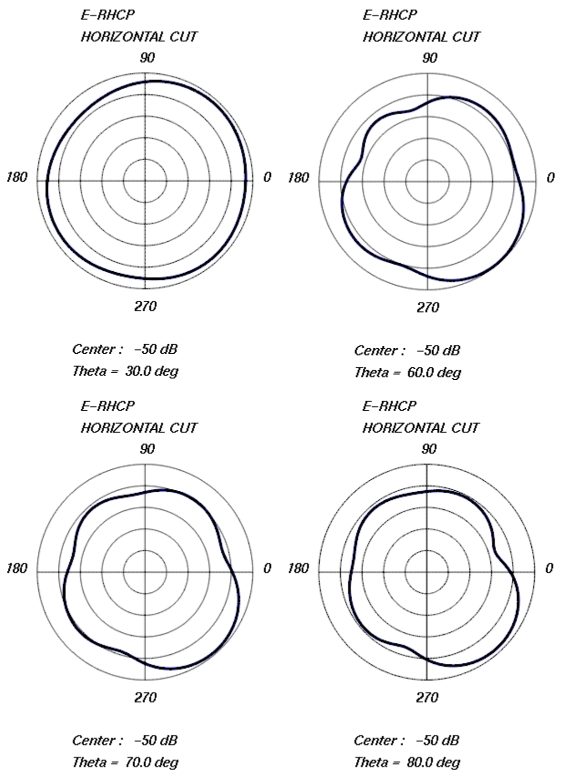

Figure 5: RHCP Gain patterns for patch element 1. The outer ring is at 0dBic, and the inner ring is at –40dBic with 10dB steps between rings. In the upper left is elevation angle 60, upper right is elevation angle 30, lower left is elevation angle 20, and lower right is elevation angle 10.

Figure 6: New Lens/Superstrate Shape. Radius Of Curvature And Height Is 1.8149 Inches, Length Of Top Flat Section Is 2.3702 Inches.

the order of -20dB, which agrees with the measured values.

The RHCP gain patterns produced from the EIGER model are shown in figure 5. Four elevation angles are shown at 60 (theta=30, upper left), 30 (theta=60, upper right), 20 (theta=70, lower left), and 10 (theta=80, lower right) degrees. The inner ring is at –40dBic and the outer ring is at 0dBic with steps of 10dB between them. The elevation patterns demonstrates that as elevation decreases from 90 degrees to 0 degrees a beam or lobe is formed in the

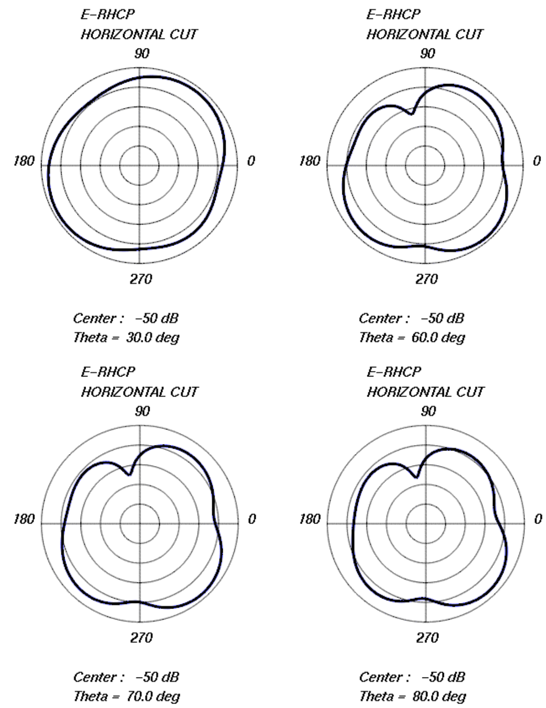

Figure 7: Same As In Figure 5 But For New Lens Configuration.

direction opposite of the location patch. In this example patch number 1 is at 135 degrees in azimuth and the lobe is at –45 degrees in azimuth. Broader side lobes are also formed that are approximately 10dB down. This effect is both from the finite ground plane as well as the lens superstrate. These effects are similar for the other patch elements and also mimic what was seen in a test of this antenna on a larger ground plane.

DESIGN REVISION TO SHAPE OF LENS SUPERSTRATE

To study the effects of the lens superstrate, a modification was made to its shape. The shape of the new lens is shown in Figure 6. Defining a radius of from the center of an element to the edge of the substrate first created the curved part of the new lens shape. This step could be interpreted as placing a hemisphere centered over each element. Once this radius was found a line was then drawn between the two tops of these hemispheres. Using the radius of the curvature, and the top line connecting them the shape of the lens was created.

When the new shape replaced the original hemisphere it was found that the patch element had to be trimmed by 3% from the original values to make the patch elements resonate at L1. The current distribution and input impedance of this configuration is similar to that of the original configuration.

Once the patches were tuned, far field patterns for each of the elements were calculated. Results are shown in Figure 7 with the same elevation cuts as was shown for the original configuration. This antenna has slightly more squint at higher elevations than the original lens shape. However, the benefit of the shape is that it is slightly shorter than the original lens.

CONCLUSIONS

The work that is on going at SPAWAR will help in the design and analysis of the NAVSYS concept of using a high dielectric superstrate lens/radome to shrink the size of CPRA antennas for use in anti-jam GPS applications where larger and heavier CRPA antennas can not be used. Currently work that is on going is examining alternate radome/lens designs for this antenna. As expected the shaping of the radome/lens is having a strong effect on the trimming of the single L1 patches. This is especially true as the top surface of the radome comes closer to the substrate layer. Two shapes currently under study include a 1.5” tall flat radome and a radome that is spherical on the sides of the radome but is flat in the center. This problem will be further complicated with the addition of the L2 patch making this a true L1/L2 stacked patch antenna. Other planned work include testing the jamming capabilities of this antenna using steady-state adaptive weights computed using the Howells-Applebaum equation for a series of jammer scenarios.

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